OCCASIONAL PIECE

Changes in technical regulations and drivers' safety in top-class motor sports

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Motor racing is a dangerous sport and an inherently risky activity. The organisers of top-class motor sports championships, Formula One and MotoGP, have agreed on a set of regulations to reduce speed and improve safety over the last 10 years. These changes include limitations in weight, fuel and engine capacity. Nevertheless, there is evidence that most of the restrictions that have been introduced over the past 10 years have failed slow down vehicles, since the lap times have decreased almost linearly from 1995 to 2006 and drivers continue to die or to sustain serious injuries that keep them away from competition. Therefore, new and efficient measures should be adopted, such as lowering the cornering speed, having heavier and safer vehicles, having barriers surrounding the track to protect both spectators and competitors better, and having innovative clothing and protective devices to defend key anatomical structures while minimising the hindrance to the rider.

Motor sports are amongst the most popular types of sports worldwide, practiced in practically all countries and as a wide variety of disciplines. Grand Prix racing refers to the premier categories of road racing worldwide, including Formula One and Moto GP. A world championship for top motorcycle racing was first organised by the Fédération Internationale de Motocyclisme (FIM) in 1949,[1] whereas the true history of Formula One began in 1946 with the Fédération Internationale de l'Automobile's (FIA's) standardisation of rules. A world drivers' championship followed in 1950.[2] Since then, these top motor racing events have become popular, attracting huge crowds at the circuits, with increasing broadcasting on television and on the web.

Grand Prix vehicles are purpose-built racing machines that are neither available for general purchase nor can be legitimately driven on public roads. As a result, these vehicles are generally made of lightweight and expensive materials, such as titanium and carbon-fibre-reinforced plastic. The main challenge that designer and engineers face in Formula One and MotoGP is to translate the enormous power of these vehicles – more than 240 brake horsepower (bhp) (179 kW) for motorcycles and 750 bhp (560 kW) for Fomula One cars – to the size of a human hand. Formula One cars produce nearly three times more power from their 2.4 litre engines, but have ten times the tyre contact surface area than do MotoGP cars. Because of this, MotoGP is unique in modern motor sports in that teams will often deliberately detune their engines to give their riders a chance to control them. The current MotoGP speed record of 347.4 km/h (215.9 mph) was set by Capirossi on a Ducati Desmosedici GP4 at International Racing Team Association (IRTA) tests in Catalunya in 2004. By way of comparison, the current Formula One speed record of 369.9 km/h (229.8 mph) was set by Pizzonia of the BMW Williams Formula One team at Monza in 2004. From a technical and spectacle point of view, the overwhelming engine power and the outstanding speeds achieved by the modern motor racing machines are at the basis of their enormous popularity, but they should also be regarded as a serious risk to the drivers' health, since there is an obvious relationship between the speed of the vehicle and either the probability or the severity of an accident.

MOTOR SPORTS ACCIDENTS

Motor racing is a dangerous sport and an inherently risky activity.[3–5] Regardless of skeletal injuries, major problems arise from the energy of impact. Due to the extraordinary speed of the modern racing machines, internal organs, head and neck can undergo dramatic decelerations up to 100 *g*,[6 7] which can generate serious and permanent lesions, as in the recent case of Ralf Schumacher, who crashed twice in the fastest section of the Indianapolis track in 2004 and 2005, sustaining serious injuries and being forced to miss the final parts of both seasons.

There is a long history of fatal accidents and injuries during races, qualifying sessions, practices and private testing sessions. Overall, the number of deaths in all forms of motor racing has increased from 28 fatalities in 1979 to 44, 45 and 37 in 2004, 2005 and 2006, respectively.[8] In Formula One, from 1954 to 1994, 27 drivers died during racing, or in free practice or qualifying sessions. Raymond Sommer was the first driver to die while driving a Formula One car in September 1950, and the last was Ayrton Senna, who died in May 1994. Seventeen drivers died in the 1950s; 13 in the 1960s; ten in the 1970s; four in the 1980s; and two in the 1990s.[8 9] The top class of motorcycling has been plagued by a majority of serious accidents, though only one rider, Daijiro Kato, was killed in racing from 1995 to 2006.[10] Hence, although 4 years have passed since the last fatal accident in the top categories of motor racing,

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Abbreviations: FIA, Fédération Internationale de l'Automobile; FIM, Fédération Internationale de Motocyclisme

several drivers are seriously injured every year. The 2006 list of injuries in MotoGP is disappointing: among others, Capirossi and Melandri suffered serious upper body injuries, Rossi fractured his hand and ankle, McWilliams sustained multiple injuries, Stoner underwent surgery for a shoulder injury, Gibernau underwent an operation to replace a plate on his collarbone, Pedrosa suffered a serious knee injury and MotoGP world champ Nicky Hayden rode the last round of the season with a broken shoulder. During the same year, former Formula One champion Jacques Villeneuve was forced to miss most of the racing season after a serious crash. Therefore, regardless of all efforts made by organising bodies and engineers to enhance safety, and of its continuous improvement throughout the last decades, motor sports will never be totally safe. Formula One and MotoGP organisers have agreed on a set of regulation changes to reduce motorcycle and racing car speeds and ensure safety (Table 1).[1 2] These include changes in weight, fuel and engine capacity.

CHANGES IN TECHNICAL REGULATIONS FOR MOTORCYCLING

MotoGP has changed dramatically in recent years. From the mid 1970s until 2002 the top class of motorcycling allowed a 0.5 litre engine with a maximum of four cylinders, regardless of whether the engine was a two-stroke or four-stroke.[2] Consequently, all machines were two-stroke, because of the greater power output for a given engine capacity. In 2002, rule changes were introduced to facilitate the phasing-out of the two-strokes, probably influenced by what was then seen as a lack of two-stroke motorcycles available to the public to buy as road bikes. The rules permitted manufacturers to choose between running two-strokes engines (0.5 litre or less) or four-strokes (0.99 litre or less). Given their extra 0.49 litre capacity advantage, the four-strokes were soon able to overlook their two-stroke rivals and consequently by 2003 no two-stroke machines remained in the MotoGP field.[10] The motorcycle's minimum weight was also restricted depending on the number of cylinders, since an engine with more cylinders for a given capacity is capable of producing more power. Precisely for this reason, the weight limit has gradually increased as a form of handicap.[2]

CHANGES IN TECHNICAL REGULATIONS FOR FORMULA ONE

A modern Formula One car is a single-seat, open-cockpit, open-wheel race car with substantial front and rear wings, and the engine positioned behind the driver. The regulations governing the cars are unique to the championship.[1] The current Formula One regulations specify that cars must be constructed by the racing teams themselves. In an effort to reduce speeds and increase driver safety, the FIA has continuously introduced new rules for manufacturers since the 1980s. Such rules have included the banning of the ''wing car'' (ground effect) in 1983, the turbo in 1989, active suspension and traction control in 1994, and the introduction of grooved tyres in 1998, and the change from V10 to V8 engines in 2006 (table 1). In 2006 the engine power was reduced from 950 bhp to 750 bhp (710 to 560 kW) by shifting from the 3.0 litre V10s, used for more than 10 years, to 2.4 litre V8s. The aerodynamic restrictions introduced in 2005 were meant to reduce downforce by about 30%. However, most teams were able to successfully reduce this loss of downforce of only 5 to 10%.[9]

PRACTICAL EFFECTS OF THE CHANGES IN TECHNICAL REGULATIONS

Despite these changes, manufacturers continue to extract performance gains by increasing power and aerodynamic efficiency. It is not easy to compare performances across several years of racing due to changes in drivers, manufacturers, teams, configuration of circuits and environmental conditions. However, there is a circuit where both the Formula One and the top class of motorcycling have both raced continuously since the early 1990s and that has not undergone changes in its configuration, allowing a reliable comparison of performances over time. The Circuit de Catalunya, a racetrack in Montmeló to the north of Barcelona (Spain) is one of the most modern tracks holding some of most important motor racing competitions. Inaugurated in 1991, the Circuit was built thanks to the Generalitat de Catalunya, the Catalan government, and the Royal Automobile Club of Catalunya (RACC) impetus. On the 29 September 1991, the 35th Formula One Spanish Grand Prix took place there. The World Motorcycling Championship was to arrive 1 year later with the European Grand Prix, which was to change its name to the Catalan Grand Prix in 1995. The most recent configuration of the track took place in 1995 and the circuit is presently 4.627 km (2.875 miles) long.[11]

Figure 1 shows the change in the best qualifying lap time during the official Formula One and motorcycling top class Grand Prix from 1995 to 2006. Regardless of the technical changes introduced to decrease speed and associated risks for the drivers, the lap time has improved almost linearly in the last 10 years for both Formula One and MotoGP. In absolute terms, Formula One cars and MotoGP bikes lapped 6.8 s and 4.5 s faster in 2006 than in 1995. In practical terms, this reflects in a percentage gain in the average lap speed of 8.4% and 4.2%, respectively, confirming that all the technical changes introduced over the past 10 years were ineffective in slowing down the vehicles.

PERSPECTIVES

Given this evidence, the future safety of drivers is again a major issue in the top categories of motor sports. To this end, the organising bodies, FIM and FIA, have both instituted a number of rule changes in recent years, including tyre and engine restrictions, and reductions on downforce. However, since the limitations were clearly ineffective (Figure 1), more radical safety regulations will be needed in the near future, covering circuits, vehicles and drivers.

Circuits

Both Formula One and MotoGP organisers have decided to remove many of the high-speed corners and replace them with chicanes.[6] To the motor sports purists, these changes are contrary to the traditions and philosophy behind racing: the greatest challenge for a driver has always been a fast, sweeping bend that can be taken at full throttle. This change has not only enraged fans and drivers alike, but is extremely inconsistent. It has been demonstrated that chicanes are not really effective in improving the safety of a racing circuit, since they reduce the risk of injury for car drivers only slightly and are mostly unsuccessful in preventing motorcycling accidents.[12] Therefore, since the redesign and deformation of traditional circuits is costly and potentially unproductive, driver safety may be improved by alternative measures that will not substantially affect the attractiveness of motor racing. These include replacing tyre barriers and metal rails with temporary crash protection barriers made of steel tubes and pads of hard foam that absorb some of the crash energy, reducing the loading to both head and neck during dramatic decelerations.[6 7]

Cornering speed

The combination of light weight, engine power, aerodynamics and ultra-high performance tyres has given top motor racing machines their high performance. Although the maximum speed of top racing vehicles has been the main target for most technical limitations introduced so far, the actual cornering

Table 1 Changes in the technical regulations for Formula One and top-class motorcycling from 1995 to 2006

Year	Formula One	Top class of motorcycling
1994	Active/reactive suspension systems banned Electronic driver aids (traction control, launch control) banned Restrictions imposed on the front and rear wings, the size and shape of the rear diffuser Airboxes 'notched' to reduce power	0.5 litre engine with a maximum of four cylinders (two-stroke or four-stroke allowed)
1995	Engines reduced to 3.0 litre capacity, ten cylinders	
1998	Grooved tyres introduced (three front, four rear) Track (width) of cars narrowed from 2 m to 1.8 m X-wings banned	
1999	Front tyre grooves increased from three grooves to four grooves.	
2000	Engines restricted to ten cylinders with a maximum of five valves per cylinder	
2001	Launch and traction control allowed again. Front wing raised to be minimum of 15 cm from ground.	
2002	Two-way telemetry introduced	0.5 litre two-stroke or 0.99 litre four-stroke engine allowed
2003	Two-way telemetry banned	Two-stroke bikes not allowed
2004	One-engine-per-weekend rule introduced Launch control banned Minimum area of rear wing endplates	Minimum weight set to 135 kg (two or three cylinder), 145 kg (four or five cylinder)
2005	One engine must last two race weekends One set of tyres for both qualifying and race.	Maximum fuel capacity reduced to 24 litres The use of any device on the motorcycle to artificially decrease the temperature of the fuel below ambient temperature is forbidden.
2006	Engines reduced to 2.4 litre capacity, eight cylinders	Maximum fuel capacity reduced to 22 litres
2007		Engines limited to 0.8 litre four-strokes Minimum weight raised to 137 kg (two cylinder), 140.5 kg (three cylinder), 148 kg (four cylinder), 155.5 kg (five cylinder) Maximum fuel capacity reduced to 21 litres

speed should be acknowledged as the main challenge. In fact, as well as being fast in a straight line, these vehicles have incredible cornering ability and they can negotiate corners at significantly higher speeds than other vehicles because of their high aerodynamic and mechanical grip. The downforce means that a Formula One car, for instance, can achieve a lateral force of about 4.5 *g* in cornering, while a high-performance road car can achieve a maximum of 1 *g*. This means that the driver's head is pulled sideways in corners with a force equivalent to 25 kg. Such lateral forces make breathing difficult, are associated with unusual disorders,[13] require extraordinary concentration to maintain the focus throughout the race and also allow a much faster exit from the corners, thus allowing driver to reach higher speeds on the following straights.

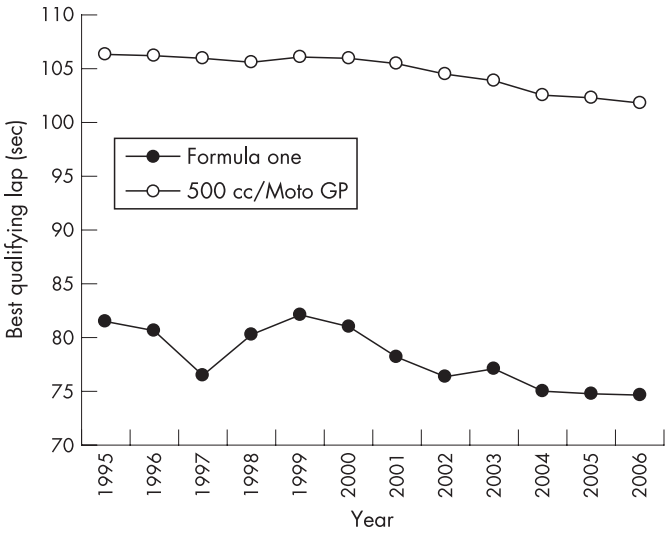

Figure 1 Changes in the best qualifying lap time in the Circuit de Catalunya during the Formula One and the top class of motorcycling Grand Prix from 1995 to 2006.

A potentially effective measure would be to further increase the weight and reduce engine power, which may encourage manufacturers to build more robust cockpits and slower competition vehicles. Such changes may even result in a better spectacle, since overtaking is easier when the overall speed decreases. Regardless of aerodynamic devices (wings), which stabilise racing cars, most of the increased cornering speed recorded over the last 10 years can be attributed to the improved mechanical grip ensured by tyres compounds unique to Formula One and MotoGP.[8–10] A racing tyre is designed to last for no more than 100–200 km and, as everything else on the vehicle, it is constructed to be as high-performance and light as possible. Therefore, if one option is slow down the vehicles in the corners to reduce number and size of the wings (which would paradoxically increase the speed on the straight), a reliable alternative that might work for both cars and motorcycles is the introduction of standard- and lower-performance tyres. The move to a single tyre-supplier for 2007 in Formula One is a preliminary step, limiting competition among tyre manufacturers and allowing the use of harder compounds (provided that engineers are not allowed to introduce new features to replace the mechanical grip).

Driver's protection

The crash tests that racing vehicles must pass have been made more stringent. The velocity used in the frontal impact test for Formula One cars has been increased from 14 m/s to 15 m/s, while the minimum size of the impact-absorbing structure has also been increased.[1] In addition, the driver's cockpit must now be clad in special anti-penetration panels made of Zylon. An additional 5 kg has been added to the car's minimum weight requirement to offset the weight of the panels. However, the recent collision in the Australian Grand Prix 2007 season-opener, with Coulthard's car lifting off, going across Wurz's Williams cockpit and nearly injuring him, highlights the need for improved protection of the driver inside the cockpit. It is an integral part of Formula One to have open cockpits; the recent introduction of head impact panel protection has improved driver safety, but there is still room for further improvement. The design of the car already includes an impact-absorbing structure at the rear behind the gearbox; a switch to closed cockpits it is not realistic, since it would go against the basic rules and regulations for a Formula One car. Nevertheless, more

effort should be placed on developing heavier and thus safer monocoques.

The reality of motorcycling is different, since no effective protection from the chassis is available to the drivers and most injuries result from violent crashes with the ground or barriers.[4 5] Moreover, it is not practical to utilise what little space is afforded within the frame of the bike to include additional safety features that would substantially interfere with the driver's ability to properly manoeuvre the vehicle, that would obstruct the driver's vision, or would otherwise cause the driver to assume an awkward or uncomfortable position. Therefore, innovative clothing designed for protection from impact or penetration should be devised. Since skeletal lesions are the most common injuries that affect pilots,[4 5] specific devices designed to restrict extreme ranges of movement that cause injury but still allow the driver enough movement to get on with driving or riding should be acknowledged. Regardless of the mandatory wearing of HANS carbon fibre collar (the HANS collar was developed in the mid 1980s by R Hubbard, Professor of biomechanical engineering at Michigan State University) in Formula One, additional thoracic, head and neck restraints are available, although they have not been applied to motor racing competitions so far. Head protection devices designed to decelerate the head in a controlled way so as to limit a sudden deceleration force on the brain during an accident are already available, as well as protective jackets that provide protection for the arms, chest, upper abdomen, back and ribs. These elements selectively defend key anatomical structures, while minimising any hindrance to the driver that would otherwise affect the ability to drive. Airbag jackets might also be helpful, since they provide protection for the front and the back of the body by a shock-buffering system, absorbing the impact with road and barriers.

CONCLUSIONS

Motor sports are inherently dangerous and if Formula One cars or MotoGP motorbikes loses control at more than 300 km/h there is very little that can be done to prevent the driver from being seriously injured. Since driver safety comes ahead of spectacle and business, it is not acceptable that drivers continue to die or be seriously injured. Drivers' injuries are an unsustainable price to pay for the show; new and efficient countermeasures need to be devised, since the decrease in the fatality rate reflects the efficacy of safety measures, even though the championship vehicles gained speed. Not only new countermeasures, but also more efficient rescue systems should be developed, but bearing in mind that excessive limitations would make the top class motor sports more like non-professional sports. Accordingly, a multifaceted strategy is likely to be the most effective: lowering the cornering speed, introducing heavier and safer vehicles, having barriers surrounding the track that would better protect both spectators and competitors, and introducing innovative clothing and protective devices that would protect key anatomical structures while minimising the hindrance to the pilot. Unfortunately, a definitive analysis of the change in safety rules that would be the most helpful and appropriate to improve the drivers' safety, perhaps through the use of statistical tools, would be biased. In fact, the accident rate, which does not depend exclusively on safety regulations, is also influenced by unpredictable factors, such as the race itself, fortuitous collisions, angle of impact and weather conditions.

What is already known on this topic

- Motor racing is a dangerous sport and an inherently risky activity.
- Appropriate regulations must be settled to reduce speed and ensure safety.

What this study adds

- Most of the restrictions introduced over the past 10 years have been ineffective in slowing down the vehicles and preventing riders' injuries.
- Not only new countermeasures, but also more efficient rescue systems should be developed, bearing in mind that excessive limitations would make top class motor sports more like non-professional sports.
- Potential safety regulations include safer protection barriers on the tracks, safer monocoques, lower performance tyres, and innovative clothing or devices designed for retention and protection from impact or penetration.

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